Fire regimes and forest structure across landscapes of Utah: A multiscale history from tree rings

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Introduction

Fire functions as a “keystone disturbance” for most natural vegetation types in western North America dictating plant community structure and the direction and pace of ecosystem processes (Frost 1998, Keane et al. 2002). The manner in which fire is manifest over time and space is collectively referred to as fire regime. Fire regime parameters are quantifiable at multiple temporal and spatial scales as frequency, seasonality, predictability, extent, and pattern (Morgan et al. 2001). An additional parameter, fire severity, is a measure of fire-induced ecosystem change (Romme et al. 2003) and may vary through time and space. Fire characteristics are affected locally by past events as well as current events on adjacent landscapes (temporal and spatial autocorrelation; Morgan et al. 2001).

Fire regimes are both heterogeneous and dynamic. Local, spatial scale variation of fire regime is related to topography (i.e. elevation, aspect, slope, connectivity, etc.) through the effects of topographic position on species composition (fuel types and arrangement), productivity, fuel desiccation rates, fuel continuity, wind speed, etc. (Swetnam and Baisan 1996, Brown et al. 2001, Heyerdahl et al. 2001). Superimposed over local variation, regional synchronization of fire patterns is driven by climate through the effects of precipitation and temperature on fuel production and desiccation. For example, in historic fire regimes of southwest pine forests, major fire years are correlated with severe drought years, particularly when preceded by 1 to 3 years of above average precipitation (Swetnam and Baisan 1996, Brown et al. 2001). This relationship is strongest for dry forest types and becomes weaker with increasing effective precipitation (i.e. elevation). Donnegan et al. (2001) observed a similar pattern for forests of central Colorado and implicated the importance of inter-annual climate cycling for the sequential production and conditioning of fuels prior to major fire events. In addition to inter-annual synchronization of fire by climate, decadal to millennial scale variation in fire occurrence has been correlated to same-scaled climate variation for western North American forests (Swetnam and Baisan 1996, Swetnam and Betancourt 1998, Grissino-Mayer and Swetnam 2000, Brown et al. 2001, Heyerdahl et al. 2002, Whitlock et al. 2003). Climate may also produce a seasonal signature in fire regime reconstructions. In the Southwest, pre-monsoonal dry lightning storms often follow warm dry spring conditions resulting in a high proportion of early season fires (Swetnam and Betancourt 1990, Swetnam and Baisan 1996, Brown et al. 2001). Conversely, late season fires become dominant at higher latitudes where springs are relatively cool and wet and fuel desiccation and thunderstorms activity is delayed (Donnegan et al. 2001, Brown and Shepperd 2001, Heyerdahl et al. 2001). North American changes in fire regime associated with Euro-American settlement and fire suppression policy implementation are well documented (Swetnam 1993, Covington and Moore 1994, Fule et al. 1997, Swetnam and Baisan 1996, Heyerdahl et al. 2001).

Fire regime reconstructions, or fire histories, are developed to describe past fire activity through one or more parameters of interest for a specific geography and time period, and are critical for understanding the relationships between fire regimes, regional and local controls, and vegetation dynamics (Morgan et al. 2001). To effectively uncover the relationship between

regional and local controls and fire regime, reconstructions must have resolution at the same scales over which variation occurs (Levin 1992). A variety of methods are employed for fire history development, each with limits in temporal and spatial resolution. Those methods capable of fixing fire events with annual accuracy are critical for elucidating fire-climate relationships at inter-annual and decadal scales. Only cross-dated dendrochronological, or tree-ring approaches are effective in achieving that level of accuracy for multi-century time periods. However, tree-ring fire frequency values are difficult to interpret due to the ambiguous associated with variation in sample area (Swetnam and Baisan 1996, Baker and Ehle 2001). Spatial resolution and interpretable frequency values can be achieved through careful selection of the size, number, and spacing of sample points across the landscape (Heyerdahl et al. 2001).

For this study we proposed to reconstruct fire and forest histories across the range of vegetation types and topography found in two watersheds on Bureau of Land Management (BLM) and state lands, or BLM lands adjacent to Forest Service watersheds that we are sampling for a broader project, funded by the Joint Fire Sciences Program, the Fishlake National Forest, and the Rocky Mountain Research Station. We are reconstructing multi-century histories of fire regimes, including variation in these regimes through time and across the landscape. We will explore the drivers of this variation (e.g., topography, soils, vegetation type, regional climate variation). With assistance from the BLM, we have selected the Wah Wah Range in the eastern Great Basin and the East Tavaputs Plateau (Book Cliffs) of the northern Colorado Plateau as two principal study locations. Sampling was completed on the Wah Wah Range in 2003. Sampling for the East Tavaputs Plateau will be completed in 2004. Additional study sites with interest to the BLM for which sampling was completed in 2003 include: Snake Range (eastern Nevada), Paunsaugunt Plateau, Henry Mountains, Abajo Mountain, and Ray Mesa (southern edge of La Sal Mountain). Data and samples from all of these sites are in various stages of preparation and analysis. The balance of this report will describe progress for the Wah Wah Mountain portion of the study.

Wah Wah Mountain Study Watershed

The study watershed is located in the Lawson Cove drainage on the north end of the Wah Wah Mountains, Millard County, Utah (Figure 1). The high point is found at the southern extreme on Ranch Peak at 2,718 m. The study portion of the watershed ranges from Ranch Peak to a low point of 2,150 m and is approximately 3.5 km long (north to south) and varies in width from 0.5 to 2 km. Total area is approximately 525 ha. Parent material is primarily limestone and dolomite with lesser amounts of volcanic dacite. Considerable rock is exposed on ridge tops, as cliff faces from 1-30 meters in height, and on talus slopes. Higher cliffs form natural boundaries for parts of the east and west sides of the study area. There is no perennial surface water within or near the study area. *Abies concolor* (white fir) is the most abundant tree species on north and east facing slopes down to about 2,300 meters and is also common in drainage bottoms at lower elevations. *Pinus monophylla* (single-needle pinyon) and *J. osteosperma* (Utah juniper) dominate lower elevations and are found throughout the study area, although largely

restricted to west and south-facing slopes and dry rocky ridges at upper elevations. *Juniperus scopulorum* (Rocky Mountain juniper) becomes common and partially replaces *J. osteosperma* at upper elevations. *Pinus ponderosa* (ponderosa pine) is found as widely scattered trees and in small, locally-dominant stands on ridge tops, east and north facing slopes and along drainage bottoms. A relatively large population (32-ha) of *Pinus longaeva* (bristlecone pine) is located on Ranch Peak, where it is variably dominant to co-dominant with *A. concolor*. Several additional clusters are scattered on north and east facing slopes generally above 2,500 m. *Pseudotsuga menziesii* (Douglas fir) is widely scattered on upper north facing slopes.

Disturbances related to Euro-American settlement and uses have been relatively light at this site (Tuhy 1985). Large numbers of domestic sheep were brought to winter in Wah Wah Valley beginning in the 1880's and continuing to the mid-1900's (Murdock and Welsh 1971). Sheep spent summer and early fall months on better-watered ranges to the east such as the Wasatch Plateau. The degree to which these herds may have penetrated into the rugged terrain of this watershed is unknown. However due to the lack of surface water, use in the past would have been limited, as it is today, to periods when snow was present (for water) but not so deep as to hinder movement and access to forage. Although sheep continue to winter in the general area (in much reduced numbers) they do not use the rugged terrain of the study area.

Methods

Field Sampling

Fire and forest history evidence was collected from 743 living and dead trees located in 24 regularly spaced plots (500 meter grid), and from fire-scarred trees found individually and in clusters outside of plots. An additional 160 samples were taken along 2 transects to improve characterization of *P. longaeva* population structure. Plot centers were located using hand-held GPS devices. For each plot, the 30 living or dead trees nearest to plot center were sampled. A minimum tree size of 20 cm diameter breast height (dbh = 1.4 m) was employed to restrict selection to older trees. Trees with excessive rot or burnout that limit the probability of successful dating were excluded.

Two types of fire evidence were collected. Partial cross-sections, including fire-scarred sections and pith, were removed from all fire-scarred trees, as evidence of non-lethal surface fires. Cross-sections and increment cores were removed from non-scarred dead and live trees to estimate pith and establishment dates. Cohort establishment dates are indicators of stand replacing events such as crown fires. Whenever possible, samples (cross-sections and cores) were removed at 10 cm above mid-slope ground level to reduce error in estimating establishment year from pith year. As cores do not always pass through pith, up to four attempts were made until a core was secured that was within an estimated 10 rings of pith for each tree. Cores were stored individually in labeled paper straws and cross-sections were labeled and wrapped in shrink wrap. Individual tree data was collected for species, condition (live, dead, bark present, eroded, etc.), distance and azimuth to plot center, dbh and diameter sample height. Plot elevation, aspect, slope, slope position, relative substrate cover (rock, bare,

forbs, grass, and shrubs), presence of charred and uncharred remnant wood, and major understory species was noted and photos were taken from plot center in each cardinal direction.

Fire-scarred trees found within 80 m of plot centers but not included in the 30-tree sample were selectively sampled to augment plot fire records resulting in a plot-centered fire scar sample area of approximately 2 ha. Additional fire-scarred trees were sampled opportunistically between plots in small clusters and as individual trees. Treatment of cluster-generated fire data will be similar to that used for fixed plots. Individual tree fire records will be used to facilitate determination of fire extent.

Sample Preparation and Analysis:

Cores were fixed on wood mounts and cores and cross-sections have been surfaced using appropriate equipment and methods. Approximately 75 percent of the samples have been cross-dated using standard dendrochronological methods (Stokes and Smiley 1968). A small percentage of the samples examined have been un-datable. Year of occurrence for approximately 385 imbedded fire scars and an additional 100 fire-related ring anomalies have been determined. Fire seasonality, as determined by within-ring fire scar position, has been assigned for approximately 70 percent of fire scars.

Fire Regime Reconstruction:

After cross-dating is completed, individual fire chronologies will be constructed for each plot and qualifying non-plot cluster by compositing fire dates identified for all trees assigned to a plot or cluster into a single fire chronology using program FHX2 (Grissino-Mayer 2001). Composite chronologies provide a longer (more years of continuous record) more complete (reduced risk of failure to identify fire events) record than do single-tree chronologies (Dieterich 1980, Swetnam and Baisan 1996). Qualifying non-plot clusters are identified as groups of sampled trees occupying a topographically uniform area of 2 ha or less (<80 m radius) and collectively possessing sufficient fire record to ensure a relatively complete record for a given time period. Mean fire interval (MFI), or the average number of years between fire dates will be calculated for each chronology. A Weibull median probability interval (WMPI) will be calculated as a second measure of fire frequency. WMPI is the estimated interval at which there is a 50 percent probability of a longer (or shorter) interval, based upon the population of intervals analyzed and is considered a more appropriate measure of central tendency in fire frequency data due to non-normal distribution of intervals around the mean (Swetnam and Baisan 1996, Grissino-Mayer 1999). When fire interval data are normally distributed then MFI and WMPI are the same. Variation in MFI and WMPI within the watershed will be used to assess the impacts of topographical elements on fire frequency. The influence of regional climate patterns on fire occurrence will be analyzed using superimposed epoch analysis (Swetnam 1993, Swetnam and Baisan 1996) in which fire years will be compared to independent tree-ring based reconstructions of Palmer Drought Severity Index (PDSI).

Post-fire survivorship of mature trees and stand recruitment, as measured by cohort extent

and dominance, will be used as indicators of fire severity. Post-fire cohorts will be identified as those trees which demonstrate a 20-40 year pulse of establishment following a known fire event. Spatial variation in fire severity will be assessed through reconstructed cohort maps and by the distribution of evidence (scarred trees) for non-lethal fires. Fire extent will be estimated (within the study watershed) for each fire from the number and spatial arrangement of fire records (plots, clusters, and minor records) assigned to the same year or season. Extent for fires recorded in a single plot or cluster will be assigned an area of 25 ha (the approximate area represented by a single plot in the grid) or less depending on the distance to significant landscape barriers to fire spread or to plots or clusters where no record of fire was observed for corresponding fire years.

Preliminary Results

Results reported here are necessarily incomplete approximations based on work in progress and are provided solely to document progress and as a crude sketch of the yet to be completed picture of fire regime for the study area. Fire frequency data reported herein are therefore subject to change as sample analysis and data are completed. No analysis of fire seasonality, extent, or severity has yet been attempted. Analysis of changes in forest structure and composition is also pending completion of sample analysis.

Sufficient fire record was found in five plots to support construction of preliminary composite fire chronologies for periods of 285 to 527 yrs (first to last record of fire; Table 1). Twelve additional chronologies for periods of 90 to 491 years are proposed for non-plot clusters of fire scar-bearing trees. Preliminary MFI values for these 17 chronologies vary from 13.3 to 67.8 years. Intervals were generally longest between 1500 and 1575 and shortest between 1650 and 1800 A.D. Periods lasting from 1400 to 1500, 1575 to 1650, and 1800 to 1830 A.D. appear to be intermediate in fire frequency. Few fire scars were found corresponding to years after 1830. Relatively strong within-plot synchrony in pith dates in 16 plots (1 to 4 cohorts per plot), and weak among-plot synchrony, suggest a spatially and temporally complex, mixed-severity fire regime across the landscape. Although fire extent has not been determined for individual fire events, the data suggest that most fires were relatively small (<100 ha) and that larger fires occurred every 50 to 150 yrs.

Evidence of fire (i.e. charred wood, scarred trees) was largely missing for seven plots. These plots were typically high in surface rock and range from 2,255 to 2,590 m in elevation. Well-spaced trees on these plots are primarily *J. osteosperma*, *J. scopulorum*, or *P. monophyla* with some *A. concolor* and *P. ponderosa*. Tree ages are old (300 to >1,000 years) and pith-date synchrony is weak or absent. Taken together, these data suggest that fire played a minimal role in the topographic units represented by these plots even though embedded in a moderate to high frequency, moderate severity fire regime background. These topographic units occur across the full elevational gradient of the study watershed and, although they are most common on dry west (and probably south) facing slopes, are strongly influenced by slope position and the soil-rock matrix. The possibility of change in susceptibility to fire of these old-

growth areas after long periods of fuels accumulation on proximal landscapes is unknown.

Literature Cited

Baker, William L. and Donna Ehle. 2001. Uncertainty in surface-fire history: the case of ponderosa pine forests in the western United States. Canadian Journal of Forest Research 31: 1205-1226.

Brown, Peter M. and Wayne D. Shepperd. 2001. Fire history and fire climatology along a 5^{o} gradient in latitude in Colorado and Wyoming, USA. Paleobotanist 50: 133-140.

Brown, Peter M., Margot W. Kaye, Laurie S. Huckaby, and Christopher H. Baisan. 2001. Fire history along environmental gradients in the Sacramento Mountains, New Mexico: Influences of local patterns and regional processes. Ecoscience 8: 115-126.

Covington, William W. and Margaret M. Moore. 1994. Southwest ponderosa forest structure. Journal of Forestry 92: 39-47.

Dieterich, John H. 1980. The composite fire interval: A tool for more accurate interpretations of fire history. Pages 8-14 *in* M.A.Stokes and J.H. Dieterich (technical coordinators). Proceedings of the Fire History Workshop, 20-24 October1980, Tucson, Arizona. General Technical Report RM-81, Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Donnegan, Joseph A., Thomas T. Veblen, and Jason S. Sibold. 2001. Climate and human influences on fire history in Pike National Forest, central Colorado. Canadian Journal of Forest Research 31: 1526-1539.

Frost, Cecil C. 1998. Presettlement fire frequency regimes of the United States: a first approximation. Tall Timbers Fire Ecology Conference Proceedings 20: 70-81.

Fule, Peter Z., William W. Covington, and Margaret M. Moore. 1997. Determining reference conditions for ecosystem management of southwestern ponderosa pine forests. Ecological Applications 7: 895-908.

Grissino-Mayer, Henri D. 1999. Modeling fire interval data from the American Southwest with the Weibull distribution. International Journal of Wildland Fire 9: 37-50.

Grissino-Mayer, Henri D. 2001. FHX2 – Software for analyzing temporal and spatial patterns in fire regimes from tree rings. Tree-Ring Research 57: 113-122.

Grissino-Mayer, Henri D. and Thomas W. Swetnam. 2000. Century-scale climate forcing of fire regimes in the American Southwest. The Holocene 10: 207-214.

Heyerdahl, Emily K., Linda B. Brubaker, and Jim K. Agee. 2001. Spatial controls of historic fire regimes: a multiscale example from the interior west, USA. Ecology 82: 660-678.

Heyerdahl, Emily K., Linda B. Brubaker, and Jim K. Agee. 2002. Annual and decadal climate forcing of historical fire regimes in the interior Pacific Northwest, USA. Holocene 12: 597-604.

Keane, Robert E., Kevin C. Ryan, Thomas T. Veblen, Craig D. Allen, Jessie Logan, and Brad Hawkes. 2002. Cascading effects of fire exclusion in Rocky Mountain ecosystems: a literature review. General Technical Report. RMRS-GTR-91. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 24 p.

Levin, Simon A. 1992. The problem of pattern and scale in ecology. Ecology 73: 1943-1967.

Morgan, Penelope, Colin C. Hardy, Thomas W. Swetnam, Matthew G. Rollins, and Donald G. Long. 2001. Mapping fire regimes across time and space: Understanding coarse and fine-scale fire patterns. International Journal of Wildland Fire 10: 329-342.

Murdock, J.R. and S.L. Welsh. 1971. Land use in Wah Wah and Pine Valleys, western Utah. Science Bulletin, Biological Series, Brigham Young University, vol. XII(4).

Stokes, Marvin A. and Terah L. Smiley. 1968. An Introduction to Tree-Ring Dating. University of Chicago Press, Chicago, IL.

Swetnam, Thomas W. 1993. Fire history and climate change in giant sequoia groves. Science 262: 885-889.

Swetnam, Thomas W. and Christopher H. Baisan. 1996. Historical fire regime patterns in the southwestern United States since AD 1700. Pages 11-32 *in* C.D. Allen (technical editor), Fire Effects in southwestern forests-Proceedings of the second La Mesa fire symposium. General Technical Report RM-GTR-286. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Swetnam, Thomas W. and Julio L. Betancourt. 1990. Fire-Southern Oscillation relations in the southwestern United States. Science 249: 1017-1020
.
Swetnam, Thomas W. and Julio L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. Journal of Climate. 11: 3128-31-47.

Tuhy, Joel S. 1985. A proposal: Research Natural Area designation for Wah Wah Mountain. USDI Bureau of Land Management, Richfield District Office. 29 p.

Whitlock, Cathy, Sarah L. Shafer, and Jennifer Marlon. 2003. The role of climate and vegetation change in shaping past and future fire regimes in the northwestern US and the implications for ecosystem management. Forest Ecology and Management 178: 5-21.

Table 1. Tentative fire frequency data for five plots and seven non-plot clusters located in the Lawson Cove watershed, Wah Wah Range, Millard County, Utah.

Plot or Cluster	Elevation (m)	Topographic Position, Aspect	Year of Fire Record First	Last	Number of Intervals	MFI (Yrs)
3B	2,370	Mid-slope, NE	1336	1863	30	17.6
3C	2,190	Cyn bottom, N	1423	1819	9	44.0
4B	2,500	Mid-slope, N	1506	1806	9	33.3
5A	2,560	Mid-slope, E	1423	1815	10	39.2
5D	2,320	Low slope, E	1533	1818	11	25.9
3A-1	2,430	Cyn bottom, N	1423	1799	7	53.7
3B-1	2,430	Mid-slope, E	1632	1796	6	27.3
6A-1	2,620	Ridge top	1506	1837	25	13.3
6A-2	2,560	Upper slope, E	1400	1891	30	16.4
7B-1	2,600	Upper slope, NE	1728	1818	5	18.0
5C-1	2,470	Mid-slope, N	1489	1763	7	39.1
3C-1	2,200	Lower slope, NE	1644	1800	8	19.5
4D-1	2,160	Cyn bottom, W	1517	1810	11	26.6
5D-1	2,310	Cyn bottom, NW	1405	1825	14	30.0
6C-1	2,560	Mid-slope, NE	1405	1765	11	32.7
6D-1	2,490	Lower slope, NW	1397	1765	8	46.0
6D-2	2,580	Mid-slope, NW	1426	1765	5	67.8
Mean					12.1	32.4

Figure 1. Perimeter of Wah Wah watershed study area located on the north end of Wah Wah Mountain, Millard County, Utah, USA.